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AN INVESTIGATION OF INSENSITIVE ELECTRIC INITIATORS
I. 1-amp/1-watt No-Fire Initiator

6 JULY 1965

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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AN INVESTIGATION OF INSENSITIVE ELECTRIC INITIATORS

I. 1-amp/1-watt No-Fire Initiator

By

Vincent J. Menichelli

ABSTRACT: The need for insensitive electrical initiators for military applications is increasing. This report describes an approach for making insensitive electric initiators. Inefficient heating of the bridge element is the key change. Various bridge heating element geometries and bridge heating element materials, with normal lead styphnate and lead azide loaded on the element were investigated. Initiators capable of passing at least 1-ampere of current and/or absorbing 1-watt of power for 5 minutes without initiating, have been developed.

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EXPLOSION DYNAMICS DIVISION
EXPLOSIONS RESEARCH DEPARTMENT
U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

 6 July 1965

AN INVESTIGATION OF INSENSITIVE ELECTRIC INITIATORS
I. 1-AMP/1-WATT NO-FIRE INITIATOR

This report is Part I of an investigation to develop insensitive electric initiators capable of passing without firing at least 1-ampere of current and/or absorbing 1-watt of power. The work was originally started under Task RREN 04004/F008-21-02(000), New Component Developments. The work is presently being funded by WepTask Explosives Research, RUME 4E000/212-1/F008-08-11, Problem No. 016, Improved Materials, Design Techniques, and Test Methods for U/W Explosive Train Components. The results should be of interest to researchers, design engineers, and component users in the field of explosives.

The identification of commercial materials implies no criticism or endorsement of these products by the Naval Ordnance Laboratory.

R. E. ODENING
Captain, USN
Commander

C. J. ARONSON
By direction

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INTRODUCTION

1. The development of insensitive initiators for military applications has been prompted primarily by safety considerations. Difficulties with conventional electroexplosive devices (EEDs) are being encountered from electromagnetic radiation, spurious electric signals, and static charges. Most conventional EEDs are now considered to be too sensitive to some of these stimuli. There are on record a number of inadvertant firings of advanced devices containing conventional EEDs. These accidents have resulted in loss of life and/or property. A number of accidents can be[1] directly attributed to the sensitivity of conventional EEDs.

2. The military has recognized this problem, and various approaches to its solution are being studied. One approach is to develop insensitive EEDs with the capability of dissipating larger than conventional amounts of electrical power or current in the bridge element without igniting the EED or affecting the reliability of the device. The Navy, in an attempt to cope with the problem, issued a military specification "Initiators, Electric, Design and Evaluation of", Mil-I-23659. This specification is not intended to be the solution to the HERO problem (Hazards of Electromagnetic Radiation to Ordnance), but it is intended to serve as a means of reducing hazards from all electrical sources. The specification has outlined tests and requirements for two classes of EEDs, the 1-amp, 1-watt device, and the exploding bridgewire device (EBW). This report is concerned with the 1-amp, 1-watt requirement only.

3. The primary electrical requirements of the specification which a 1-amp, 1-watt device must meet are as follows:

(a) The bridge element must be capable of passing 1-ampere of current or absorbing 1-watt of power, whichever is greater, for 5 minutes at an ambient temperature of 225°F without initiating.

(b) The device must reliably initiate from 5-amperes of current or 5-watts of power, whichever is smaller, at an ambient temperature of -80°F within 50 milli-seconds.

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1. Investigation of Premature Explosions of Electroexplosive Devices and Systems by Electromagnetic Radiation Energy (U), Paul C. Constant, Jr., Billy L. Rhodes, George E. Chambers, Midwest Research Institute, April 1962 (Confidential)

The other requirements of the specification, such as rough handling and surveillance tests, generally, could be met utilizing present know-how. It was the purpose of this study to develop a means of meeting the firing and non-firing requirements of Mil-I-23659.

4. Prior to the publication of Mil-I-23659, preliminary work was already underway to develop an initiator which was capable of passing 1-ampere of current or 1-watt of power, whichever was greater, without causing ignition. Some success was achieved when a flat printed circuit type bridge element was substituted for the conventional cylindrical wire bridge element. A standard glass-to-metal seal initiator plug as shown in Figure 1 was used as the test vehicle. The bridge element was designed to give the maximum length and surface contact area practicable on the face of the plug. The configuration of the bridge element is shown in Figure 2. Evanohm, Alchrome, and Cupron alloys were the materials from which the elements were fabricated. These materials were selected because of their high specific resistivity and low thermal coefficient of resistivity. Additional information on these alloys is given in Appendix A. It was intended to hold the bridge resistance between 3 and 7 ohms and to load conventional primary explosives such as normal lead styphnate and lead azide on the bridge heating element. When a bridge element fabricated from Evanohm alloy was soldered to the pins of the glass initiator plug, a resistance of 4.36 to 4.62 ohms resulted. Subsequently, the length of the bridge was shortened for reasons which will be explained later. As the effective length of the bridge was shortened, the size of the soldering tabs was increased. It was felt that increasing the mass of metal at the solder posts would result in more efficient heat sinks.

5. With the issuance of Mil-I-23659, the approach to developing an insensitive initiator had to be revised because an upper as well as a lower limit on current and power was imposed. The upper and lower current and power limits given in Mil-I-23659 were plotted as a function of current and bridge resistance. Figure 3 shows the plot and the envelope formed by the limits. The largest spread in the envelope between the all-fire and no-fire curves occurs at 0.2 ohm. As the bridge resistance increases from 0.2 ohm, the power, which at this point is the controlling factor for the all-fire limit, requires that the current decrease exponentially until it converges with the 1-amp no-fire limit at five ohms. At this point, the initiator must always fire and never fire, which of course, is absurd. As the bridge resistance decreases from 1-ohm, the power is the controlling factor for the no-fire limit, and it increases exponentially. At 0.04-ohm resistance, the current necessitated by the 1-watt no-fire control limit crosses the 5-ampere all-fire current. From an examination of the plot, it appears that the bridge resistance which would most easily allow meeting of the firing and non-firing requirements

of Mil-I-23659, is approximately 0.2 ohm because the largest spread between all-fire and no-fire limits exists here.

6. Initiators as shown in Figure 4 were assembled with milled normal lead styphnate or dextrinated lead azide loaded at 20,000 psi onto the bridge element. At first, nylon charge holders were used, but during the no-fire tests (1 watt or 1 amp for five minutes) the charge holders became distorted and began to deteriorate. Aluminum was substituted for the nylon, eliminating the problem, and also affording a good heat sink. The various bridge elements were then tested in accordance with the all-fire and no-fire requirements of Mil-I-23659.

TEST EQUIPMENT

7. The bulk of the testing was carried out using two different constant current source instruments. One instrument converts a storage battery source into a constant current source with an equivalent internal resistance of approximately 500 ohms. It can be continuously adjusted to current levels up to 5 amperes, and the stability is primarily limited by thermal drift in the output power transistor circuit. The circuit, shown in Figure 5, derives standard voltage from one or two 6-volt dry cells which provides a reference voltage of 6 or 12 volts. By setting the helipot, a fraction of this voltage is fed into the double emitter follower. This circuit tries to keep the voltage drop across its emitter load (3 ohms) equal to the input voltage (e_r). Thus, the collector or EED current is closely equal to $e_r/3$. A mercury switch throws the reference voltage into the circuit and starts the EED current. The current rise time is about 40μs. An R-c lag network connected to the helipot tap eliminates any overshoot due to helipot inductance. The 100-ohm resistor also limits bridging current in the mercury relay. Since temperature rise and the associated collector leakage current of the 2N174 establish the drift, a large heat sink and fan are employed. Voltage for the relay is obtained from a full-wave voltage doubler circuit.

8. The second instrument was a constant current, millisecond, pulse-driven mercury switch. It is possible to pre-select a "close time" between the limits of 10 and 250 milliseconds or close the switch continuously during no-fire or set-up conditions. The pulse time has a variability of about ± 0.5 millisecond primarily resulting from variations in the mercury relay pull-in or drop-out levels. A voltage drop of 100 millivolts at 5 amperes was observed corresponding to a maximum switch resistance of 200 milliohms. Switch closure is approximately 2 microseconds or less and the contacts have been protected for a 5-ampere level at 30 volts. The timing is accomplished by a packaged D.C. pulse switch (Microswitch No. 1PB3002) which is a transistorized monostable

multivibrator circuit and has a basic time of 75 milliseconds. By removing the internal timing capacitor and resistor, the basic time of 75 milliseconds can now be made variable from front panel controls. This switch is driven from a regulated power supply designed to deliver 18 volts at 100 milliamperes or more. Each time the pulse switch is closed, the mercury switch is pulsed "on" for the preset time. A circuit diagram is shown in Figure 6.

TEST RESULTS

9. The data have been grouped according to bridge element design and bridge material. The ordering is not necessarily the sequence in which the tests were conducted. In all cases, the bridge element width was 10 mils and the thickness 1 mil. Each bridge element was soldered to the pins of the glass initiator plug and an aluminum charge holder attached. Milled normal lead styphnate or dextrinated lead azide was loaded onto the bridge at 20 K and 10 K psi, respectively.

10. Bridge element #1, as shown in the insert was constructed from Evanohm, Alchrome, and Cupron alloys. The resultant bridge resistance for each material was as follows:

Evanohm - 4.3 - 4.5 ohms
Alchrome- 4.8 - 5.0 ohms
Cupron - 1.7 ohms

Element #1

Work with this bridge element was done prior to the issuance of Mil-I-23659. Consequently, the upper firing limit had not yet been imposed and there was no need to place an upper limit on the bridge resistance. Initiator assemblies were tested by applying a constant current for five minutes or until ignition occurred. The results given in Table 1, show, as one would expect, that the initiator assemblies containing milled normal lead styphnate were more sensitive than those containing lead azide. The assemblies containing elements made from Evanohm and Alchrome alloys responded similarly, with Alchrome being slightly more sensitive. Neither alloy could pass more than 0.6 ampere for 5 minutes for normal lead styphnate or 0.8 ampere for lead azide without igniting the charge. The Cupron Circuits were capable of passing 1-ampere for 5 minutes without igniting the normal lead styphnate and 1.4 amperes for 5 minutes without igniting the lead azide.

11. The bridge element resistance for Evanohm and Cupron alloys was reduced by modifying the effective bridge length as

shown in the insert. The resulting bridge resistances were as follows:

Element #2

Evanohm - 2.1 ohms

Cupron - 0.7 ohms

Initiator assemblies were loaded and tested in the same manner as above. The results given in Table 2 show that with this design, Evanohm with normal lead styphnate was able to pass 0.9 ampere for 5 minutes without firing and 0.95 ampere with lead azide for 5 minutes without firing. With lead styphnate this represents about a 50% increase in current over the previous design. Lead azide showed an improvement of only 19%. Cupron passed 1.7 amperes with normal lead styphnate and 2.0 amperes with lead azide for 5 minutes without igniting the charges. This represents about a 70% increase with lead styphnate, while the result with lead azide was less dramatic with only a 42% increase.

12. The resistance of the bridge was further reduced by modifying the design as shown in the insert and was tested as before. The resulting bridge resistances were as follows:

Element #3

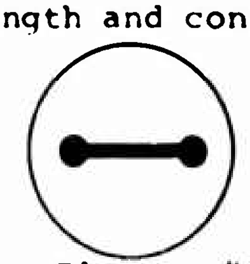
Evanohm - 1.3 ohms

Alchrome- 1.2 ohms

Cupron - 0.4 ohms

The results given in Table 3 show that Evanohm was marginal in passing 1-ampere of current for 5 minutes with normal lead styphnate on the bridge. With lead azide on the bridge, 1.2 amperes were passed for 5 minutes without ignition. Alchrome behaved similarly to Evanohm passing 1.1 amperes with normal lead styphnate and 1.3 amperes with lead azide on the bridge for 5 minutes without ignition. Cupron was tested with normal lead styphnate only, and demonstrated that it could pass 1.6 amperes for 5 minutes without ignition. It was obvious that with lead azide on the bridge it would equal and probably better these results.

13. Further reduction of the bridge length and consequently, a reduction in the bridge resistance was accomplished by merely using ribbon (1-mil thick x 10-mils wide) made from the alloys, soldered directly across the initiator plug pins, as shown in the insert.



Element #4

The resulting bridge resistances were as follows:

Evanohm - 0.3 ohms

Alchrome- 0.3 - 0.44 ohms

Cupron - 0.1 - 0.2 ohms

Evanohm could not pass 1-watt of power for 5 minutes without firing with either normal lead styphnate or lead azide on the bridge. Alchrome failed to pass 1-watt of power for 5 minutes with normal lead styphnate on the bridge, but did meet this requirement with lead azide. With normal lead styphnate on the Cupron bridge, it failed to pass 1-watt of power for 5 minutes. With lead azide on the bridge, it was capable of passing 1.2-watts of power for at least 6.67 minutes. The results of this testing are given in Table 4.

14. The functioning timesof the four designs were also determined when 5-watts of power or 5-amperes of current, whichever was less, was delivered. The functioning times reported in Tables 5 through 8 decrease as the bridge resistance decreases and the current increases. In general, normal lead styphnate functions sooner than lead azide for the same bridge element and input conditions. However, in the case of the Cupron Element #1, normal lead styphnate functioned much slower than did lead azide. A summary of the bridge elements and their ability to meet the all-fire and no-fire stimulus requirements of Mil-I-23659 is given in Table 9.

DISCUSSION

15. An approach to developing an insensitive initiator has been taken, which differs from the conventional, in that a ribbon instead of a wire is used as the bridge element. The ribbon was chosen in lieu of the wire because of the greater peripheral area available from the ribbon for a given cross section. For example, a ribbon 1-mil thick by 10-mils wide has a perimeter of 22 mils, while a wire of the same cross sectional area (3.6-mils diameter) has a circumference of 10-mils. By comparison, there is twice as much surface area per unit length exposed with the ribbon than with the wire. To carry this a step further, a ribbon 0.5-mils thick by 20-mils wide has a perimeter of 41 mils, while still maintaining the same cross sectional area mentioned above. The increase in surface area has the advantage of allowing a greater dissipation of heat per unit mass of bridge element.

16. The four bridge elements with the exception of Element #4 were fabricated by a photo etching process. The materials were obtained from the Sigmond Cohn Corporation, Mount Vernon, New York, in sheet form (1-mil thick) and supplied to the Chem Fab Corp., 16 Donaldson Street, Doylestown, Pa., with a scaled sketch of the element. The sketch was optically reduced to the desired dimensions

and the photo etching process followed. This method proved very successful in producing uniform elements and is very well adopted to mass production. Element #4 is made by drawing the material to the desired width and thickness.

17. The three bridge wire materials tested can meet the 1-amp, 1-watt no-fire requirement with normal lead styphnate loaded on the bridge element. The advantage in the choice of bridge material would depend on the bridge resistance one is interested in obtaining. If higher bridge resistances are desired, some advantage can be had by loading lead azide on the bridge. The all-fire within 50 milliseconds requirement was only met when 5-amperes of current was used to initiate. There are many applications where functioning time must be very short, i.e., microseconds. In those applications the ribbon design could not be expected to be applicable.

18. The manner in which the 1-amp, 1-watt requirement is achieved is by efficient heat loss from the bridge element to the surrounding medium. An attempt has been made to apply a simple mathematical model to the system studied. Constant current, long time inputs without end effects are assumed. Under these conditions, temperature equilibrium is established, and the electrical power input is equal to the rate of heat loss. The following expression may be written:

$$I^2R = HSL\Delta T \tag{1}$$

where
- I = Current
- R = Resistance of Bridge Element
- S = Perimeter of Bridge Element
- L = Length of Bridge Element
- ΔT = Temperature Rise of Bridge Element
- H = Heat Transfer Constant

also

$$R = \frac{\rho L}{A} \tag{2}$$

where
- ρ = Specific Resistivity of the Bridge Material
- A = Cross Sectional Area of Bridge Element

substituting

$$I^2 \frac{\rho L}{A} = HSL\Delta T \qquad (3)$$

$$I^2 = \frac{HSA\Delta T}{\rho} \qquad (4)$$

let

$$\frac{H}{\rho} = K\text{, a Constant} \qquad (5)$$

then

$$I^2 = KSA\Delta T \qquad (6)$$

Now with the same bridge material and explosive, ΔT for constant current firing should approach a constant value so that

$$I = (K_2 SA)^{1/2} \qquad (7)$$

where $K_2 = K\Delta T$

Equation (7) says that the firing current is proportional to the square root of the product of the cross sectional area and the perimeter. For two different size ribbon

$$\frac{I_1^2}{I_2^2} = \frac{S_1 A_1}{S_2 A_2} \qquad (8)$$

The above equations have not been verified experimentally, but further work will be directed to this end.

19. The work to date has suggested a number of new experiments and concepts for exploration. For instance, future work will be directed toward the development of a detonator capable of meeting the requirements of Mil-I-23659, based on the information from this study. The relationship of bridge circuit configuration and material to current and power requirements will also be investigated.

CONCLUSIONS

20. A study of insensitive initiators has been made by substituting ribbon shaped bridge elements for the conventional cylindrical wire bridges. Initiators capable of passing 1-ampere of current and absorbing 1-watt of power have been demonstrated.

These initiators have bridges made from various materials and shapes. Primary explosives such as normal lead styphnate and lead azide can be used on the bridge elements.

21. The author wishes to acknowledge with gratitude the many helpful suggestions and the guidance furnished by Mr. I. Kabik of this Laboratory, and Professor L. Rosenthal of Rutgers University.

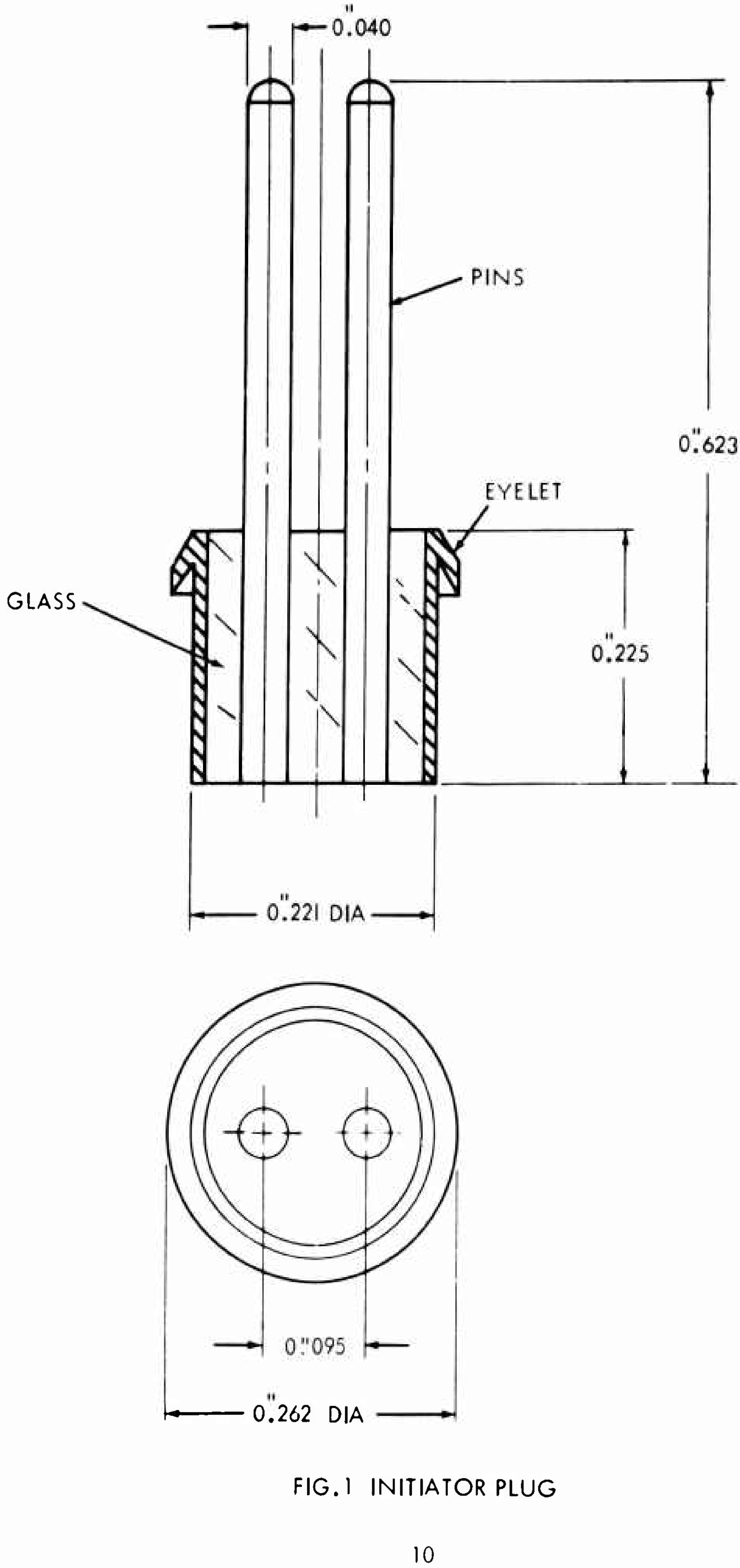


FIG. 1 INITIATOR PLUG

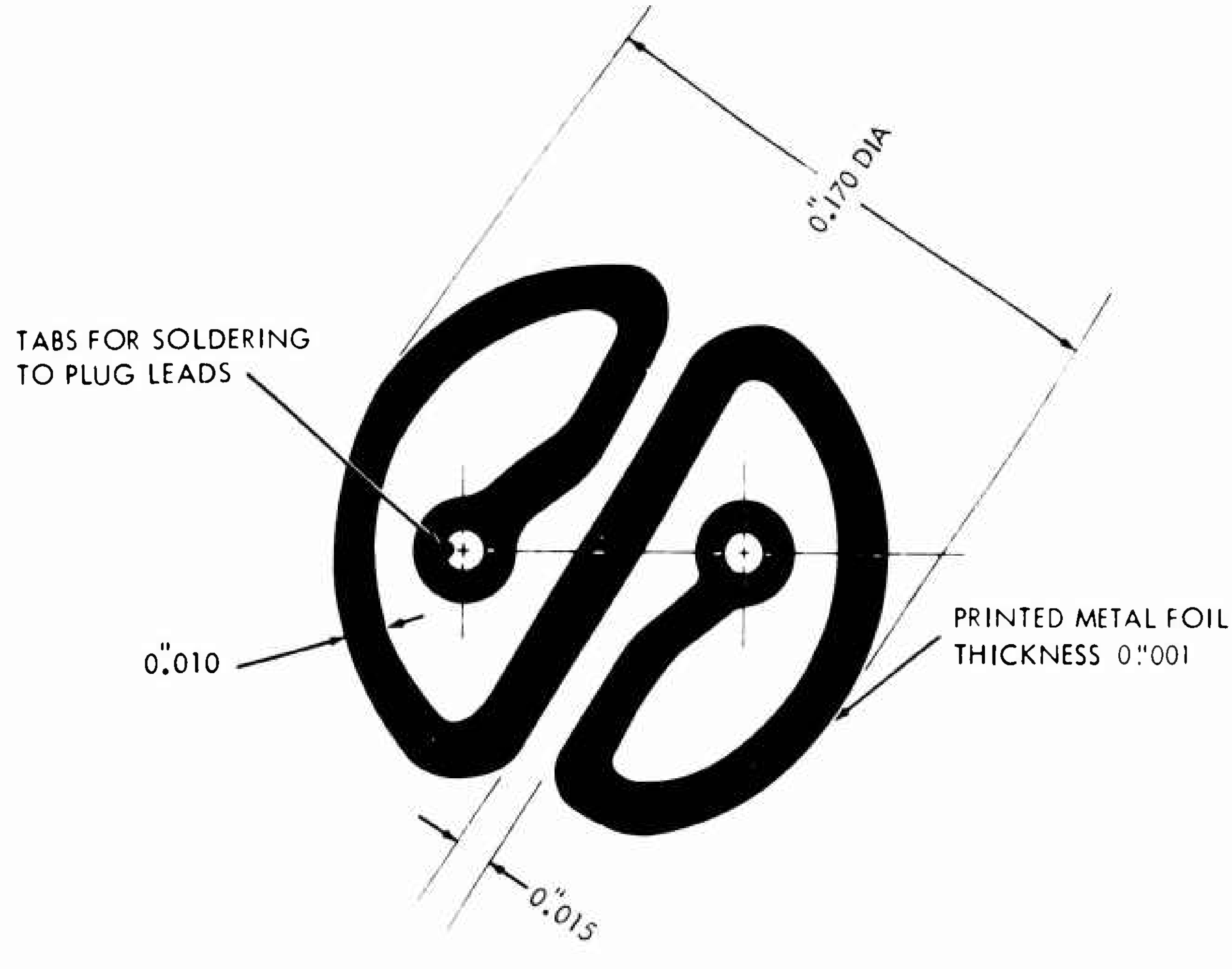


FIG. 2 BRIDGE ELEMENT

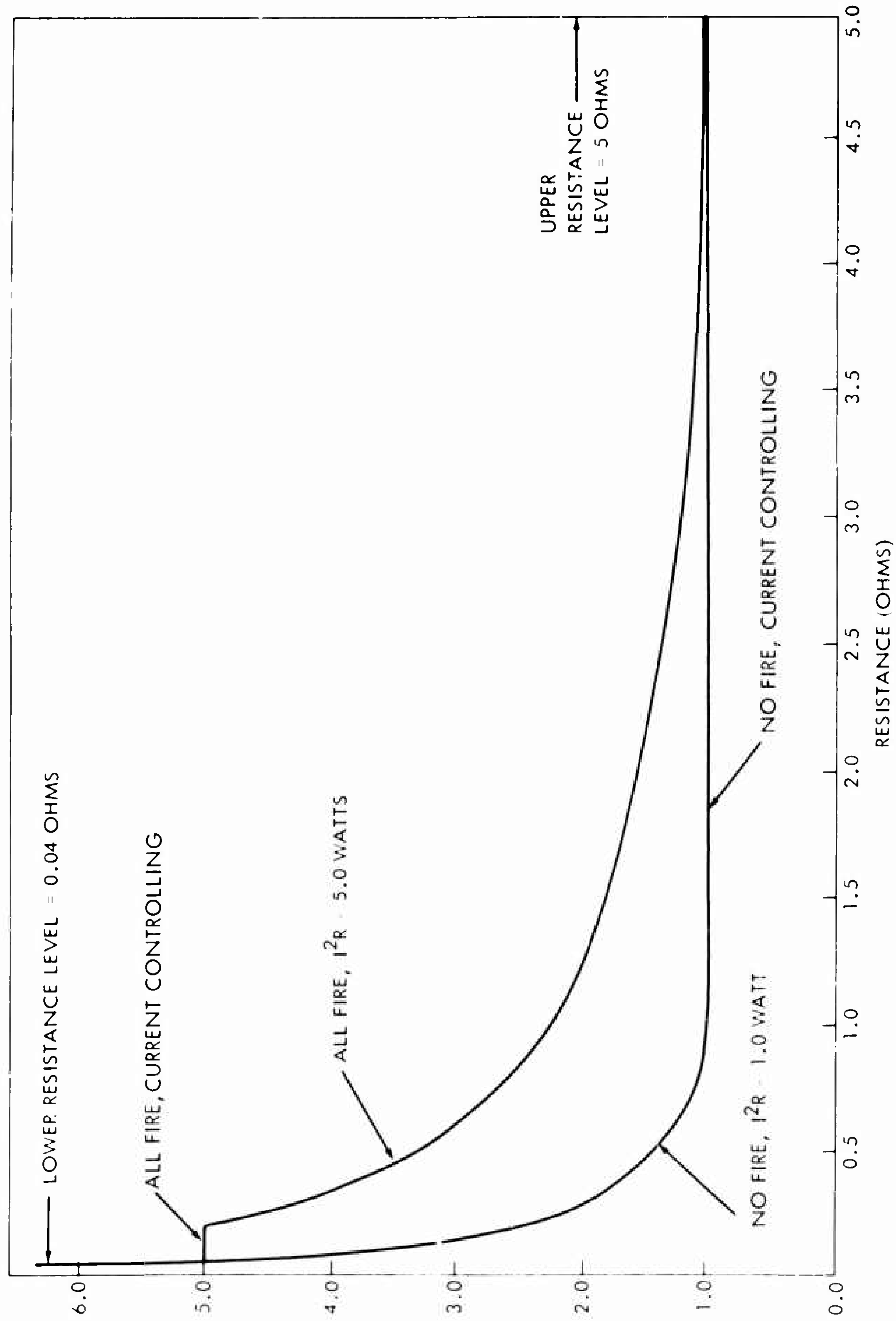


FIG. 3 NO FIRE AND ALL FIRE RESISTANCE LIMITS

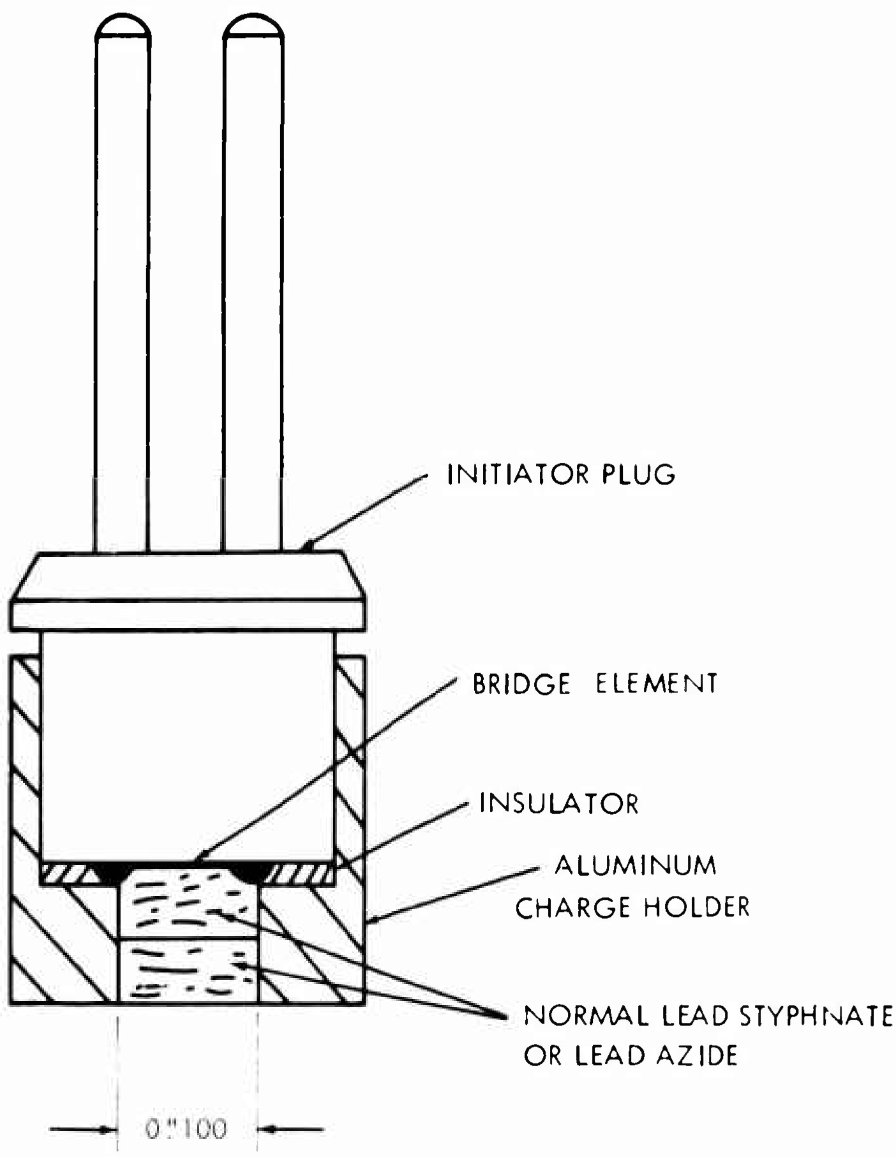


FIG. 4 INITIATOR ASSEMBLY

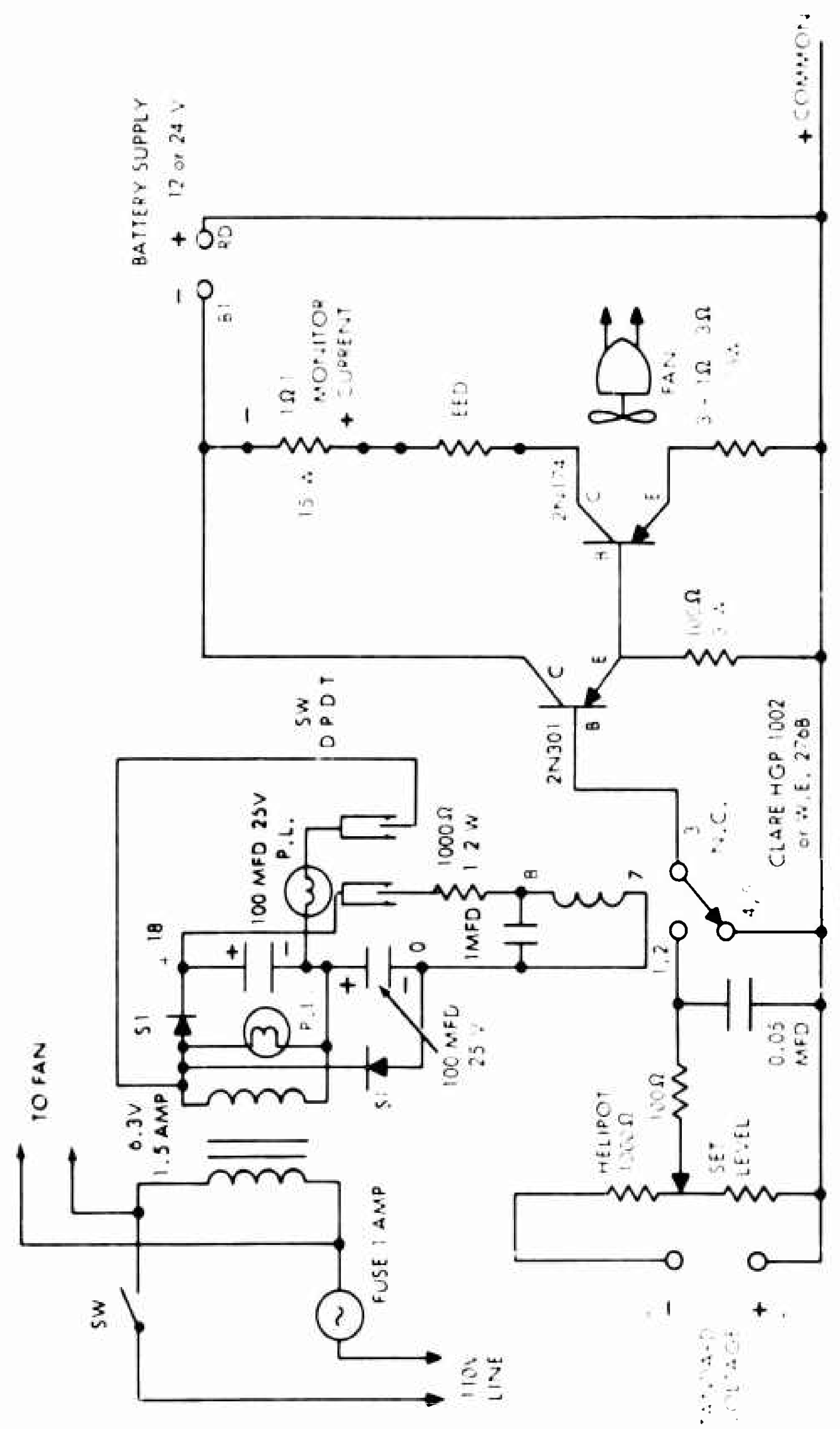


FIG. 5 CONSTANT CURRENT SOURCE

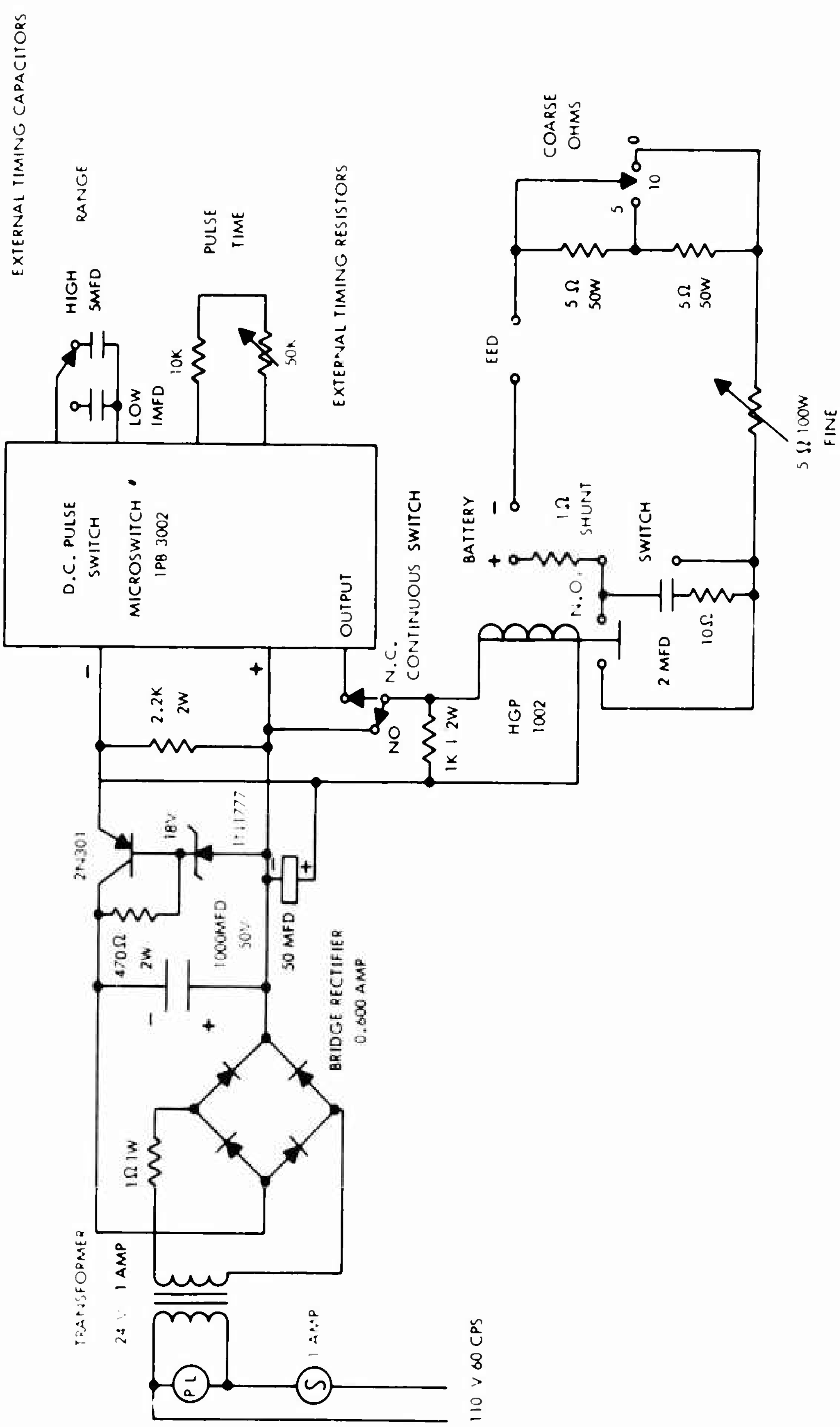


FIG. 6 CONSTANT CURRENT MILLISECOND SWITCH

Table 1. Constant Current Test Results for Bridge Element #1

	Normal Lead Styphnate on Bridge					Dextrinated Lead Azide on Bridge				
Bridge Material	Resistance (ohms)	Current (amps)	Power (watts)	Time (min)	Results	Resistance (ohms)	Current (amps)	Power (watts)	Time (min)	Results
Evanohm	4.5	0.7	2.2	1.75	Fired	4.5	1.0	4.5	0.75	Fired
	"	0.65	1.9	3.6	Fired	"	0.9	3.6	1.3	Fired
	"	0.6	1.6	5.0	No Fire	"	0.8	2.9	5.0	No Fire
Alchrome	5.0	0.6	1.8	3.0	Fired	4.8	1.0	4.8	0.5	Fired
	5.0	0.5	1.25	5.0	No Fire	"	0.9	3.88	0.85	Fired
						"	0.8	3.07	1.75	Fired
Cupron	1.7	1.1	1.87	5.0	No Fire	1.7	1.5	3.82	1.5	Fired
	1.7	1.05	2.05	3.5	Fired	1.7	1.4	3.32	5.0	No Fire
	1.7	1.0	1.7	5.0	No Fire	1.7	1.2	2.45	5.0	No Fire

Table 2. Constant Current Test Results for Bridge Element #2

	Normal Lead Styphnate on Bridge					Dextrinated Lead Azide on Bridge				
Bridge Material	Resistance (ohms)	Current (amps)	Power (watts)	Time (min)	Results	Resistance (ohms)	Current (amps)	Power (watts)	Time (min)	Results
Evanohm	2.1	0.95	1.9	3.9	Fired	2.1	1.0	2.1	1.5	Fired
	2.1	0.9	1.7	5.0	No Fire	2.1	0.95	1.9	5.0	No Fire
	2.1	0.8	1.3	5.0	No Fire					
Cupron	0.7	1.8	2.27	1.9	Fired	0.7	2.2	3.4	1.0	Fired
	0.7	1.7	2.02	5.0	No Fire	0.7	2.1	3.09	1.0	Fired
	0.7	1.6	1.80	5.0	No Fire	0.7	2.0	2.8	5.0	No Fire
	0.7	1.5	1.58	5.0	No Fire					
	0.7	1.1	0.85	5.0	No Fire					

Table 3. Constant Current Test Results for Bridge Element #3

Bridge Material	Normal Lead Styphnate on Bridge					Dextrinated Lead Azide on Bridge				
	Resistance (ohms)	Current (amps)	Power (watts)	Time (min)	Results	Resistance (ohms)	Current (amps)	Power (watts)	Time (min)	Results
Evanohm	1.3	1.0	1.3	3.3	Fired	1.3	1.3	2.2	1.1	Fired
	1.3	1.0	1.3	5.0	No Fire	1.3	1.2	1.87	5.0	No Fire
	1.3	0.95	1.2	5.0	No Fire	1.3	1.1	1.58	5.0	No Fire
						1.3	1.0	1.3	5.0	No Fire
Alchrome	1.2	1.2	1.73	2.0	Fired	1.2	1.4	2.35	0.5	Fired
	1.2	1.1	1.45	5.0	No Fire	1.2	1.3	2.03	5.0	No Fire
	1.2	1.0	1.20	5.0	No Fire	1.2	1.2	1.76	5.0	No Fire
Cupron	0.4	1.60	1.0	5.0	No Fire					
	0.4	1.60	1.0	5.0	No Fire					
	0.4	1.58	1.0	5.0	No Fire					

Table 4. Constant Current Test Results for Bridge Element #4

	Normal Lead Styphnate on Bridge					Dextrinated Lead Azide on Bridge				
Bridge Material	Resistance (ohms)	Current (amps)	Power (watts)	Time (min)	Results	Resistance (ohms)	Current (amps)	Power (watts)	Time (min)	Results
Evanohm	0.3	1.85	1.02	0.4	Fired	0.3	1.85	1.02	<0.02	Fired
Alchrome	0.3	1.85	1.02	0.07	Fired	0.3	1.85	1.02	5.0	No Fire
	0.37	1.7	1.0	*0.266	Fired	0.3	1.85	1.02	5.0	No Fire
	0.44	1.5	1.0	*0.258	Fired					
Cupron	0.1	3.15	0.99	0.13	Fired	0.10	3.15	0.99	5.0	No Fire
						0.10	3.15	0.99	5.0	No Fire
						0.20	2.23	1.0	5.0	No Fire
						0.11	3.0	1.0	5.0	No Fire
						0.13	2.75	1.0	6.67	No Fire
						0.11	3.15	1.1	6.67	No Fire
						0.12	3.15	1.2	6.67	No Fire
						0.13	3.15	1.3	4.77	Fired

* Seconds

Table 5. Functioning Time for Bridge Element #1

Bridge Material	Normal Lead Styphnate on Bridge				Dextrinated Lead Azide on Bridge			
	Resistance (ohms)	Current (amps)	Power (watts)	Time to Fire (seconds)	Resistance (ohms)	Current (amps)	Power (watts)	Time to Fire (seconds)
Evanohm	4.3	1.1	5.0	4.8	4.3	1.1	5.0	31
	4.3	1.1	5.0	5.8				
Alchrome	5.0	1.0	5.0	4.0	5.0	1.0	5.0	20
	5.0	1.0	5.0	8.0	5.0	1.0	5.0	28
Cupron	1.7	1.7	5.0	19	1.7	1.7	5.0	0.39
	1.7	1.7	5.0	14	1.7	1.7	5.0	0.40

Table 6. Functioning Time for Bridge Element #2

Bridge Material	Normal Lead Styphnate on Bridge				Dextrinated Lead Azide on Bridge			
	Resistance (ohms)	Current (amps)	Power (watts)	Time to Fire (seconds)	Resistance (ohms)	Current (amps)	Power (watts)	Time to Fire (Seconds)
Evanohm	2.1	1.55	5.0	<1	2.1	1.55	5.0	<1
	2.1	1.55	5.0	0.266	2.1	1.55	5.0	0.250
	2.1	1.55	5.0	0.151	2.1	1.55	5.0	0.170
Cupron	0.7	2.68	5.0	0.242	0.7	2.68	5.0	40
	0.7	2.68	5.0	0.226	0.7	2.68	5.0	34

Table 7. Functioning Time for Bridge Element #3

	Normal Lead Styphnate on Bridge				Dextrinated Lead Azide on Bridge			
Bridge Material	Resistance (ohms)	Current (amps)	Power (watts)	Time to Fire (seconds)	Resistance (ohms)	Current (amps)	Power (watts)	Time to Fire (seconds)
Evanohm	1.3	1.96	5.0	0.074	1.3	1.96	5.0	0.080
	1.3	1.96	5.0	0.073	1.3	1.96	5.0	0.120
	1.3	1.96	5.0	0.070				
	1.3	1.96	5.0	0.036				
	1.3	1.96	5.0	0.113				
Alchrome	1.2	2.02	5.0	0.089	1.2	2.02	5.0	0.151
	1.2	2.02	5.0	0.089	1.2	2.02	5.0	0.106

Table 8. Functioning Time for Bridge Element #4

	Dextrinated Lead Azide on Bridge			
Bridge Material	Resistance (ohms)	Current (amps)	Power (warrs)	Time to Fire (Microseconds)
Alchrome	.3	5.0	7.0	30
	.3	4.0	4.8	9
	.3	4.0	4.8	20
	.3	4.0	4.8	20
Cupron	.2	5.0	5.0	46
	.2	5.0	5.0	30
	.2	5.0	5.0	14
	.2	5.0	5.0	20
	.2	5.0	5.0	30

Table 9. Ability to Meet the All-Fire and No-Fire Stimulus Requirements of Mil-I-23659

Bridge Element	Explosive Material	Bridge Element Material		
		Evanohm	Alchrome	Cupron
1*	NLS	NO	NO	YES**
	PbN_6	NO	NO	YES**
2	NLS	NO	NO	YES**
	PbN_6	NO	-	YES**
3	NLS	NO	YES**	YES***
	PbN_6	YES**	YES**	-
4	NLS	NO	NO	NO
	PbN_6	NO	YES	YES

NLS - Normal Lead Styphnate
PbN_6 - Lead Azide

* These results obtained prior to issuance of Mil-I-23659
** Functioned in greater than 50 milliseconds
*** No Functioning times available

APPENDIX A

Alloy Trade Name	Normal Composition	Resistivity at 20°C		Temperature Coefficient of Resistivity	
		ohms/CMF	Microhm cm	ohms/ohm per Deg.C.	Temp. Range Degrees C.
Evanohm	75% Ni - 20% Cr 2.5% Al - 2.5% Cu	800	134	± 5 x 10^{-6}	-65 to + 125
Alchrome	79.5% Fe - 15% Cr -5.5% al	825	137	± [illegible] x 10^{-5}	25 to 100
Cupron	55% Cu -45% Ni	294	48.4	± [illegible] x 10^{-5}	25 to 100

1. Source: Wilbur B. Driver Company